

# ELECTRONIC CIRCUIT FOR ION SENSOR

## BACKGROUND OF THE INVENTION

### Field of Invention

The invention relates to an ion sensing circuit, and more particular to a circuit adopting  
5 Ion-Sensitive Field Effect Transistors that is compatible with CMOS technology and  
implemented by integrated circuits.

### Related Art

Silicon-based semiconductor micro sensors are now able to react to the ion concentration  
(activity). The Ion-Sensitive Field Effect Transistor (ISFET), which is a micro sensing  
10 element combining electrochemistry with microelectronics technology, was introduced in the  
1970s. The ISFET selectively senses the ion concentration in an electrolyte. The ISFET is a  
trans-resistance element, which has the features of low output impedance of MOSFET and  
operation of Ion Selective Electrode (ISE). The ISFET has features of rapid reaction time,  
high sensitivity, batch processing, small size and single chip integration. Furthermore, it can  
15 be implemented by CMOS technology. These advantages make it the first choice for VLSI  
electrochemistry sensing array.

Compared with MOSFET, ISFET replaces the metal or polysilicon gate with electrolytes  
and reference electrode. Different concentration of electrolyte components causes  
corresponding variations of the threshold voltage of the ISFET. Through the reaction of the  
20 sensing membrane and the electrolyte, the concentration of  $H^+$  or other ions can be acquired  
by sensing circuits.

Many sensing circuits based on the above concept have been proposed in the prior art.  
One of which is shown in Fig. 1. The sensing circuit of Fig. 1 detects the ion concentration of  
the solution with features of constant voltage/constant current operation mode, and floating  
25 reference electrode. The drain terminal of the transistor ISFET is connected to the output  
terminal of the first amplifier OP1, where a constant voltage, e.g., 0.7 volts in the figure, is

fed to its positive terminal. The negative terminal is connected to the output terminal. The source terminal of the transistor ISFET is coupled with the negative terminal of the second amplifier OP2, and coupled with the ground via a resistor R. A constant voltage, e.g., 0.5 volts in the figure, is fed to the positive terminal of the second amplifier OP2. The output terminal of the second amplifier OP2 is coupled with the reference electrode Ref of the transistor ISFET. With this configuration, two constant voltages input to the two positive terminals of the amplifiers cause the source terminal S and the drain terminal D of the transistor ISFET to keep a constant drain-source voltage difference. The solution of the ion concentration creates the connection between the reference electrode Ref and gate sensing membrane (terminal G). The potential difference between the gate sensing membrane and the reference electrode Ref is determined by the ion concentration of the solution.

The sensing circuit in Fig. 1 is easy to be implemented by integrated circuits. The measured signal is the output from the amplifier OP2 connected with the reference electrode Ref.

However, once the sensing circuit in Fig. 1 is applied to multiple sensors or sensor arrays, since one reference electrode is necessary for each transistor ISFET, the increasing number of sensors leads to increasing number of reference electrodes. This is not economically viable, and is not suitable for mass production or commercial development.

The circuit in Fig. 2 adopts one sensing circuit for all the sensors, i.e., only one reference electrode is used to detect the ion concentration. The circuit in Fig. 2 is composed of a first transistor ISFET1 and a second transistor ISFET2. The drain terminals of the two transistors are connected together. The drain terminal of the transistor ISFET1 is coupled with the output terminal of the first amplifier OP1, where a constant voltage, e.g., 0.7 volts in the figure, is fed to its positive terminal. The negative terminal of the first amplifier OP1 is connected to the output terminal. The source terminals of the two transistors coupled with analog switches CH1 and CH2 respectively, which are switched by a multiplexer. The switches CH1 and CH2 are also coupled with the negative terminal of the second terminal OP2. The negative

terminal is also coupled with the ground via a resistor  $R$ . A constant voltage, e.g., 0.5 volts in the figure, is fed to the positive terminal of the second amplifier OP2, whose output terminal is coupled to the reference terminal. The two constant voltages input to the two positive terminals of the amplifiers cause the source terminal and the drain terminal of the transistor ISFET to keep a constant voltage difference.

The main advantages of the circuit in Fig. 2 are reduced chip size and power consumption. However, the problems of the conductivity of the switches, the rising temperature upon switching and noise interference need to be solved. Furthermore, only one ISFET operates at one time. Sufficient stable time is needed before switching to the next ISFET so all the sensors cannot operate at the same time. The situation is more serious when the number of ISFETs in the sensor array increases. The detected signal implies the drift error of the ISFET owing to the switching time for completing the detection by ISFETs.

The multiple sensing circuit presented in Fig. 2 has essential drawbacks. The supplying voltage is multiplexed by CH1 and CH2 from ISFET1 to ISFET2 and both ISFETs cannot be supplied simultaneously. This may cause instability of the output signal  $V_{out}$  due to transient processes resulting from the switching. Another drawback is increasing of measuring time resulting from the serial mode of operation and the above-mentioned transient processes.

Therefore, for overcoming of the above-mentioned drawbacks, another circuit is proposed in Fig. 3. The configuration of this circuit involves grounding the reference electrode and a bridge-type circuit with a floating voltage source.

The bridge-type configuration includes a current source  $I_{ref}$ , a constant voltage source that is generated together with a variable resistor  $R_v$ , and an operational amplifier OP. The Zener diode ZN1 provides a specific reference voltage. The operational amplifier OP, the resistor  $R_a$ ,  $R_b$ , and  $R_c$ , and the ISFET form an electrical bridge network. The advantage of this configuration is grounding the reference electrode  $Ref$ , so that the only one reference electrode is necessary for multiple ISFET detection. The circuit has a wide range of operations and is suitable for ISFETs with unspecified characteristics. However, the Zener

diode ZN1 needs a special manufacture technology, and the voltages of its two sides are floating. The circuit in Fig. 3 is not suitably implemented by a standard CMOS technology.

### SUMMARY OF THE INVENTION

5 The main object of the invention is to provide an ion sensing circuit that grounds the reference electrode and bridge-type sensing circuit with a floating reference voltage source. The disclosed circuit can be implemented or mass manufactured with integrated circuits by CMOS technology, which is the main bottleneck of the prior art, and is also applicable to sensor arrays.

10 To achieve the objects of the invention, the disclosed sensing circuit includes a bridge sensing circuit and a differential amplifying circuit. The bridge circuit senses the ion concentration in constant drain-source voltage and constant drain current mode of operation of the transistor ISFET. The differential amplifying circuit amplifies the output of the bridge type sensing circuit and stabilizes the transistor ISFET drain-source voltage  $V_{DS}$  and drain current  $I_{DS}$  due to feedback loop operation of the amplifier and constant value floating  
15 reference voltage that supplies the bridge.

A reference voltage generating circuit is also disclosed by the invention for generating the reference voltage  $V_{ref}$ . The reference voltage generating circuit is composed of a plurality of resistors, an amplifier, and a Zener diode such that parts of the components can be manufactured by integrated circuit technology. In the second preferred embodiment of the  
20 reference voltage generating circuit, the reference voltage generating circuit includes a plurality of resistors, an amplifier, and bipolar junction transistors. All the components in the second embodiment can be implemented by integrated circuits.

The disclosed sensing circuit is able to acquire signals from enhancement or depletion mode type ISFET-based sensors or sensor arrays with no switching time delay and in wide  
25 operation range, no matter whether the sensing membranes of the ISFETs are known or unknown. Meanwhile, only one reference electrode is needed for the disclosed sensing circuit such that the circuit is easily implemented by CMOS technology. The circuit can be also

applied to the ISFET-based multiple sensors or sensor arrays.

Furthermore, the disclosed ion sensing circuit acquires all the ISFET signals with no switching delay time. The circuit also can be promoted to satisfy the industry demands in mass production of ISFETs for more rapid, stable and accurate detection of their characteristics.

Further scope of applicability of the invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

Fig. 1 is the sensing circuit of the prior art, whose characteristics include constant drain-source voltage, constant drain current, and floating reference electrode;

Fig. 2 is another sensing circuit of the prior art, whose characteristics include electrode;

Fig. 3 is the sensing circuit of the prior art, whose characteristics include constant drain-source voltage, constant drain current, and bridge-type sensing circuit with floating reference voltage, and grounded reference electrode;

Fig. 4 is the ion sensing circuit of the first embodiment of the invention, with the characteristics of reference electrode grounding and bridge-type sensing circuit, and bridge-type floating reference voltage source;

Fig. 5 is the reference voltage generating circuit accompanying the first embodiment of the invention; and

Fig. 6 is the sensing circuit of the second embodiment of the invention, with the characteristics of reference electrode grounding and bridge-type sensing circuit, and

bridge-type floating reference voltage source with the bandgap voltage reference circuit.

## DETAILED DESCRIPTION OF THE INVENTION

Fig. 4 illustrates the ion sensing circuit of the invention. The circuit in Fig. 4 can be implemented by integrated circuits. Bridge architecture is adopted in the bridge sensing circuit, in which the reference electrode Ref is grounded and the source terminal of the transistor ISFET floats due to its threshold voltage variation, which is output signal Vout.

The disclosed sensor can be placed directly into a solution. When the analyte to be measured reacts with the sensing membrane, the variation of the electric potential at the interface sensing membrane/solution results in changes of the gate-source voltage of the transistor ISFET and output signal Vout. The transistor ISFET is one kind of ion sensing element, which modulates the resistance of the channel between the drain and the source due to changes of the ion concentration in the solution.

As shown in Fig. 4, the bridge sensing circuit 100 is a bridged type circuit, which is composed of a first impedance element R1, a second impedance element R2, a third impedance element R3, an Ion-Sensitive Field Effect Transistor ISFET, and a first amplifier OP1. The first amplifier OP1 is one kind of operational amplifier. The first impedance element R1 and the second impedance element R2 are connected in serial, and the third impedance element R3 and the transistor ISFET are connected in serial. The two serial circuits are connected in parallel. The positive terminal of the first amplifier OP1 is coupled between the first impedance element R1 and the second impedance element R2, while the negative one is coupled between the third impedance element R3 and the drain terminal of the transistor ISFET. The output terminal of the first amplifier OP1 is coupled between the second impedance element R2 and the source terminal of the transistor ISFET. The reference electrode Ref is connected to the ground. Since the output signal Vout is measured between ground and the source terminal of the transistor ISFET, the source terminal is floating. Compared with the prior art, not only the disclosed circuit but also the multiple sensing circuit need only single reference electrode to detect the concentration of several analytes.

Owing to the balanced condition of the bridge network and the virtual short circuit of the input terminals of the operational amplifier, the constant voltage  $V_{DS}$  of the transistor ISFET is generated, and the constant current  $I_{DS}$  through the transistor ISFET is determined by the third impedance element  $R_3$ . Therefore, the transistor ISFET is operating in the constant drain-source voltage and constant drain current conditions.

The drain of the transistor ISFET is connected through the third impedance element  $R_3$  to the terminal  $T_{in}$ , while its source terminal is connected to  $T_{out}$ . The differential amplifying circuit 200 is composed of a second amplifier OP2 and four impedance elements  $R_4$ ,  $R_5$ ,  $R_6$  and  $R_7$ . The second amplifier OP2 is one kind of operational amplifier.

A first capacitor  $C_1$  is coupled between the positive terminal of the first amplifier OP1 and the ground, while a second capacitor  $C_2$  is coupled between the negative terminal of the first amplifier OP1 and the output terminal  $T_{out}$ . Both capacitors are used as bypass capacitors.

The two input voltages of the differential amplifying circuit 200 are the reference voltage  $V_{ref}$ , which is fed to the negative terminal of the amplifier OP2 via the fourth impedance element  $R_4$ , and the output voltage  $V_{out}$  from the bridge sensing circuit 100, which is fed to the positive terminal of the amplifier OP2 via the fifth impedance element  $R_5$ . The sixth impedance element  $R_6$  is coupled between the positive terminal of the second amplifier OP2 and the ground. The seventh impedance element  $R_7$  is coupled between the negative terminal and the output terminal of the amplifier OP2.

The transistor ISFET operates in the constant drain-source voltage and drain current mode, in which the conversion of chemical signal to electric one has the highest accuracy. Compared with the prior art, the invention adopts a differential amplifying circuit 200 to couple with the bridge sensing circuit 100, whose the balance condition causes the transistor ISFET to operate in the constant drain-source voltage and constant drain current mode, thereby detecting the accurate electrolyte concentration.

The voltage generating circuit 400 is illustrated in Fig. 5. Besides the bridge sensing circuit 100 and the differential amplifying circuit 200, the circuit in Fig. 5 further includes a follower type impedance converter circuit 300 and a voltage generating circuit 400. The voltage generating circuit 400 delivers constant voltage, which is amplified as the reference voltage  $V_{ref}$  of Fig. 4 by the follower type impedance converter circuit 300. The follower type impedance converter circuit 300 is composed of a third amplifier OP3, which is one kind of operational amplifier. The output terminal of the amplifier OP3 is fed back to its negative terminal. The voltage generating circuit 400 includes a Zener diode ZN2. A tenth impedance element R10 is connected in serial between the P type side of the diode ZN2 and a negative voltage source  $V_{ss}$ . An eighth impedance element R8 is connected between the N type side and the positive terminal of the third amplifier OP3, while a ninth impedance element R9 is connected between the P type side and the positive terminal of the third amplifier OP3. Both of the impedance elements R8 and R9 create a voltage divider.

The N type side of the diode ZN2 in the voltage generating circuit 400 is connected with the ground, while the P type side is connected with a negative source  $V_{ss}$ . Comparing the circuit 400, in which one side of the diode ZN2 is connected to the ground, with the prior art presented in Fig. 3, where both sides of the Zener diode ZN1 are floating, the generated voltage of the invention is more stable, and is amplified by the follower type impedance converter circuit 300, as the reference voltage for the differential amplifying circuit 200. The drawback of not being manufactured by CMOS technology of Zener diode ZN1 is thus avoided.

In the application of multiple sensors or sensor arrays, only one sensing circuit and only one reference electrode are needed for all ISFETs. Each ISFET has an independent signal reading circuit. The signals from multiple sensors or sensor arrays with unspecified sensing membranes could be acquired without delay of switching time.

Fig. 6 illustrates the second embodiment of the invention. Besides the advantages of circuit shown in Figs. 4 and 5, the circuit in Fig. 6 is totally implemented by integrated circuit,



and is economically viable.

The voltage generating circuit 500, which is one kind of bandgap voltage reference circuit, includes a first bipolar junction transistor Q1, and a second bipolar junction transistor Q2. The base terminals of the two transistors are connected with each other and connected to the ground. The collector terminals of the two transistors are connected to the ground. The emitter terminal of the first transistor Q1 is coupled to the positive terminal of the fourth amplifier OP4. The emitter terminal of the second transistor Q2 is coupled to the negative terminal of the fourth amplifier OP4 via a thirteenth impedance element R13. An eleventh impedance element R11 is connected between the output terminal and the positive terminal of the fourth amplifier OP4, while a twelfth impedance element R12 is connected between the output terminal and the negative terminal of the fourth amplifier OP4.

The second embodiment shown in Fig. 6 employs a bandgap voltage reference circuit to produce a stable voltage, which is independent of temperature and the voltage source. The differential amplifying circuit and the bridge sensing circuit are also included such that all the circuits can be implemented by integrated circuits, thereby forming an ISFET signal readout circuit with the features of a grounding reference electrode and floating source terminal. Once the disclosed voltage generating circuit in Fig. 6 is applied to the sensing array circuit, only one bandgap voltage reference circuit of the second embodiment is needed.

Nowadays to satisfy biomedical application a large number of simultaneously operating sensors is required. The disclosed ion sensing circuit enables multisensing measurement by ISFETs with improved reliability and stability. The main feature of the disclosed circuit is a bridge-type floating voltage source with wide operation range. The circuit is easily implemented by CMOS technology. The disclosed sensing circuit is able to acquire signals from enhancement or depletion mode type ISFET-based sensors or sensor arrays with no switching time delay and wide operation range, no matter whether the sensing membranes of ISFETs are specified and unspecified. Compared with the conventional circuits using floating gates-source voltage, because in the disclosed sensing circuit the reference electrode

is grounded, which means that only one reference electrode is needed for ISFET-based multiple sensors or sensor arrays.

Furthermore, the disclosed ion sensing circuit acquires all ISFET signals with no switching delay time. The circuit can also be promoted to satisfy the industry demands in  
5 mass production of ISFETs for more rapid, stable and accurate detection of their characteristics.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are  
10 intended to be included within the scope of the following claims.